Microscopic Calculation of the Pre-equilibrium Emission for Neutron Scattering on Actinides

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When a nucleon collides with a target nucleus, several reactions may occur: elastic and inelastic scatterings, charge exchange, multiple particle emissions, etc. To explain the particle emissions, three nuclear reaction processes are involved: the direct process, the pre-equilibrium or pre-compound emission, and the formation and evaporation of a compound nucleus. Moreover, for heavy elements like actinides (^{238}U, ^{232}Th, etc.), a fission process takes place and more particles are emitted. Here we focus on the neutron-induced reactions on ^{238}U in the energy range 10-20 MeV. To predict the energy spectrum and the angular distribution of the emitted neutrons, one has to use several nuclear reaction models to take into account the different reaction processes. However, these models rely on adjustable parameters, which are usually tuned to reproduce the experimental data. Consequently, the evaluation of the emission spectrum remains ambiguous, and no reliable extrapolation can be made to domains when there is no experimental data. The example of neutron scattering on actinides is very important—the experimental data are scarce, but accurate evaluations are needed for applications like neutron moderation in nuclear reactors.

Hence, more predictive evaluations are really needed. For this purpose, we have achieved a calculation of the pre-equilibrium emission that does not require any adjustment to the experimental data. The cross-section for neutron emission is computed from all possible transitions between the target ground state and excited states, which follow the collision between the target and the projectile. These transitions are calculated within a quantum mechanical framework—wave functions of the target states are obtained with a deformed Hartree-Fock calculation, and we use a nuclear two-body interaction obtained from microscopic calculation to generate the transitions. We present in Fig. 1 the energy distributions obtained for the scattering of 14 MeV neutrons on the ^{238}U target. For the same reaction, we depict in Fig. 2 the angular distribution of 7.5 MeV outgoing neutrons. On these figures, we have added the contribution coming from the evaporation and fission processes. Our pre-equilibrium calculations reproduce the energy and angular distribution very well without any fitting to the experimental data—this is good progress in the area of pre-compound reaction modeling.

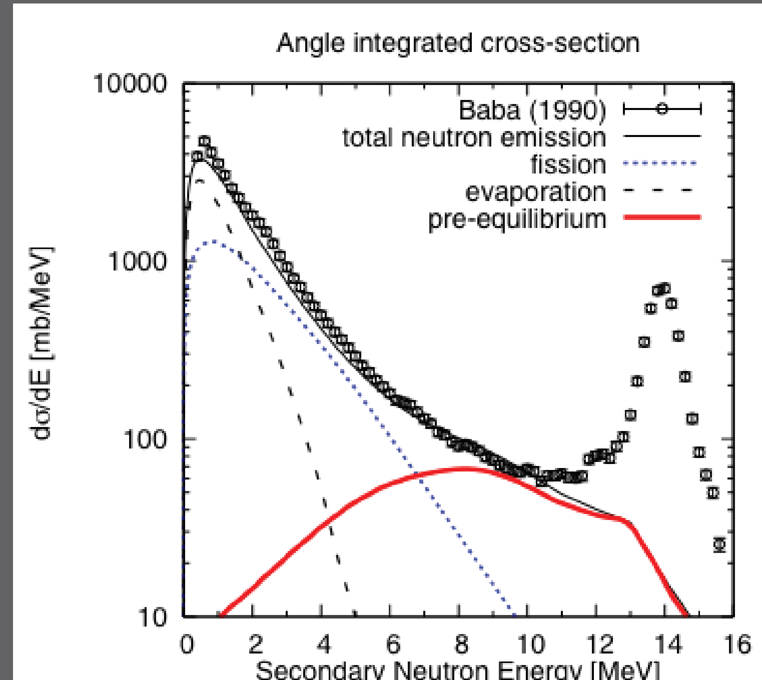

Fig. 1. Angle integrated neutron emission spectrum for 14 MeV neutron scattering on ^{238}U.

Microscopic calculations will also be needed to describe the other processes to get a precise prediction of the whole energy spectrum. Indeed, the models of compound nucleus and fission use many phenomenological parameters. Better calculations of direct processes, which contribute to the high energy part of the neutron spectrum, are also needed since they are performed with phenomenological interactions and a crude description of the target states. More predictive calculations of the fission and the direct processes could be performed with an accurate description of the target ground and excited states. A precise structure description of heavy elements is still very difficult, but the new computer capacities allow us to consider such calculations.

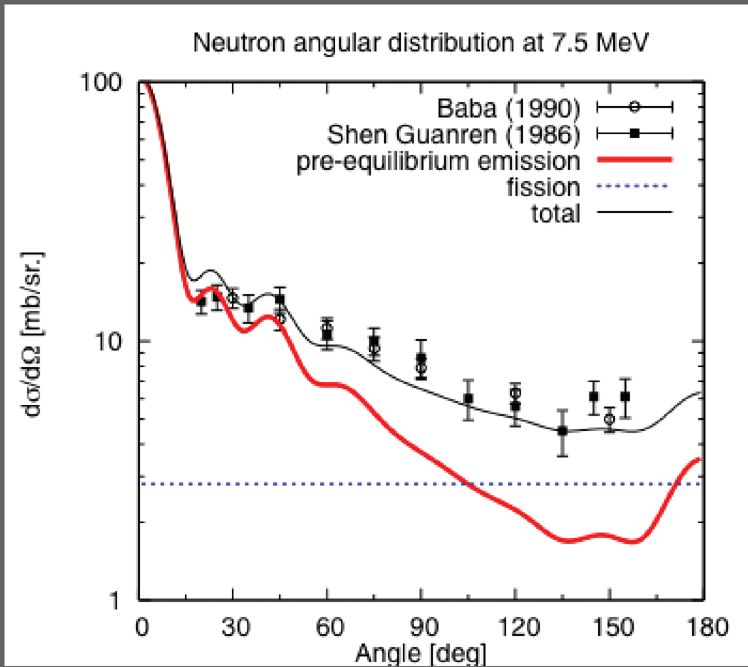

Fig. 2. Angular distribution of emitted neutron at 7.5 MeV for 14 MeV neutron scattering on ^{238}U.

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